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# Heat Stress in Mining

U.S. Department of Labor
Mine Safety and Health Administration
National Mine Health and Safety Academy

Safety Manual No. 6

Revised 1989

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U.S. Department of Labor
Elizabetn Dole
Secretary

Mine Safety and Health Administration
David C. O'Neal
Deputy Assistant Secretary

Safety Manual No. 6

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Ancient miners from a Greek vase. (From "Man and Metals" by T.A. Ricket. Copyright 1932, McGraw-Hill Company. Used with permission of McGraw-Hill Book Company.)

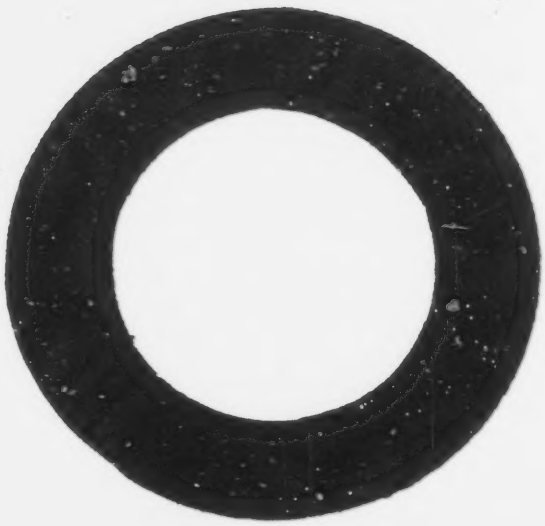
## PREFACE

*Historically the engineer has made mining possible for human beings. Today the proper object is to provide conditions in which the miner is a contented individual operating at maximum efficiency.*

P. R. Davis and A. A. Knight
Ergonomics of Mining, **Medicine in the Mining Industries**
J.M. Rogan, ed., F. A. Davis Company, 1972

This is one of the series of pamphlets prepared by the technical staff of the National Mine Health and Safety Academy to acquaint the reader with a specific area of mining. This pamphlet deals with the nature of heat stress and strain and the mechanism of heat control in the human body. The signs of heat-related physiological disorders and the first aid for heat stress victims are described, and the stress control measures in mines are noted.

This is a revised version of a pamphlet originally published under the same title in 1976. Since then, no new heat stress studies have been made in mining. Other pamphlets in this series are listed on the inside back cover. Individual copies may be obtained from any district office of the Mine Safety and Health Administration (MSHA) or from the National Mine Health and Safety Academy, P.O. Box 1166, Beckley, West Virginia 25802-1166.



## CONTENTS


| | page |
|---|---|
| Introduction | 1 |
| Why the Concern About Heat Stress | 3 |
| How Human Body Copes With Heat Stress | 5 |
| Control of Heat Stress in Mining | 13 |
| Heat Disorders—First Aid for Heat Stress Victims | 23 |
| Summary | 29 |
| Bibliography | 30 |
| Glossary of Terms | 31 |

**Persons working in hot, humid work sites tend to ignore unsafe working situations.**

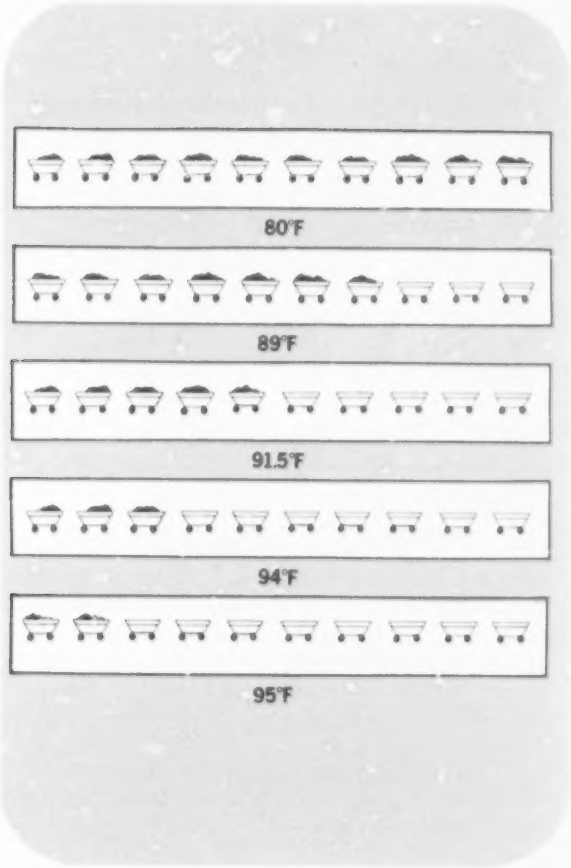
## INTRODUCTION

*There is the right of every red-blooded man to be assured that his work will be a daily satisfaction to himself; that it is a work which is contributing to the welfare and advance of his country; and that it will build for him a position of dignity and consequence among his fellows.*

Herbert C. Hoover,
**Principles of Mining,**
McGraw-Hill Book Co., Inc.
1909

*Enforcement is a good principle which can only be effective when accompanied with a good education and training effort, an effort to educate the miners in the health hazards, an effort to train miners on the importance of maintaining a healthy environment, an effort to motivate the miners to know and play a major role to improve the environment in mines.*

Robert E. Barrett, Administrator,
Mining Enforcement and Safety
Administration, **Annual Meeting of the American Public Health Association,** 1976




**In an experiment, a number of miners were loading mine cars in a moisture-saturated work site at various environmental temperatures. The work output of miners dropped from 100 to 20 percent as the air temperature was raised from 80 to 95°F.**

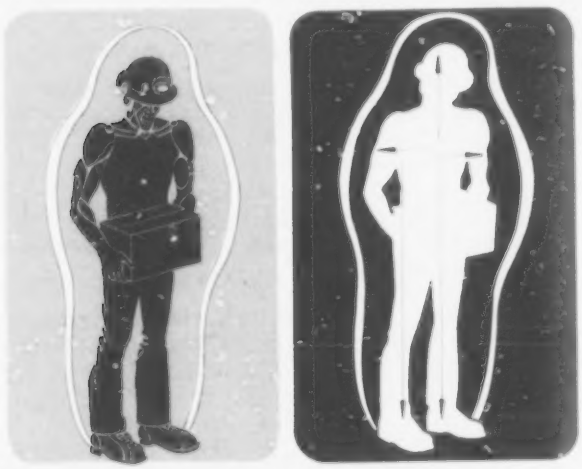
## WHY THE CONCERN ABOUT HEAT STRESS

Deep mines and mines sunk in hot countries are hot work sites. Some underground mines in moderate geographic zones are hot because of the unusually high heat flow from the earth. Many mines in the southwestern United States are located along a high heat zone. The thrust for the development of new sources of minerals calls for an expansion of underground mining in deeper, and therefore, hotter levels of the earth crust.

In mining, as in other industries, the exposure of workers to very hot conditions is unhealthy and unproductive. Persons working in hot, humid work sites tend to be inefficient; quite often workers prefer to stay away from work or ignore unsafe working situations. Studies in South African gold mines have shown that high temperatures reduce the work output of miners.

Dexterity and coordination, ability to observe irregular, faint optical signs, ability to remain alert during lengthy and monotonous tasks, and the ability to make quick decisions are adversely affected by the heat strain. For example, in a 3-hour drilling operation performed under varying room temperatures, the best results were obtained at 84° F; the performance was reduced to 75 percent capacity at a room temperature of 91° F, to 50 percent at 96, and to 25 percent at 99° F. For a new employee, 77° F room temperature is the upper limit for best performance. Heat strain can also show itself in the form of irritation, anger, and other emotions leading to rash acts by persons performing hazardous jobs. The lowest accident rates have been related to men working at temperatures below 70°F, the highest to temperatures of 80°F and over.

There is some evidence that older persons have a lower tolerance for heat. They start to sweat later than do younger individuals. It takes longer for body temperature to return to normal levels in older individuals exposed to heat stress. In one study the majority of all the individuals who fell victim to heatstroke were over 60 years of age.



**The body metabolism provides heat and energy for our physiological functions. When the environment is cooler than our body, part of the excess body heat is lost to the environment through convection and radiation. An active person loses part of his body heat through evaporation. However, in a hot environment the body gains heat from the environment through convection and radiation.**

**The body core can dissipate its heat only through the shell. Blood serves as a vehicle for heat transfer.**

## HOW HUMAN BODY COPES WITH HEAT STRESS

Warm-blooded animals can function regularly in almost all types of weather and climate because they can maintain their body temperature within a narrow range. Carbohydrates, fats and proteins in our food provide energy for our daily activities. The human body, like mechanical devices and machines, is not 100 percent efficient. At best, only 25 percent of the energy generated by the body's metabolism is converted into mechanical work. Thus, at least 75 percent of the energy produced by metabolism is converted into heat which is needed to support the metabolic process. However, too much heat will interfere with the metabolism and cause health problems such as heatstroke, fainting, exhaustion, cramps and water deficiency.

### Heat Control In The Human Body

The human body may be thought of as having a core and a shell; this assumption will make it easier to understand the heat control in the body. The core contains the deep muscles and tissues, including the heart, lungs, abdominal organs, and brain. The shell contains the skin, tissues forming the skin base, and the muscles close to the skin; the hands and feet are also part of the body shell.

Rectal temperatures are a measure of the core temperature. At rest, the body core temperature remains almost uniform. Under extreme conditions—from sleeping in a cold environment to doing hard work in a hot work site—the core temperature varies from 95 to 104°F.

The health of a person at work and at rest depends upon the stability of the core body temperature. The core **cannot** store an excessive amount of heat without upsetting its delicate temperature balance. Oral temperatures are a measure of core and the shell temperatures; the body core can dissipate its heat only through the shell. Blood serves as an effective vehicle for heat transfer between the body core and the shell.

**Human body at rest will dissipate the heat generated by metabolic process. Evaporation, convection and radiation are the methods of body heat dissipation.**

### Dissipation of Heat From Human Body

Two or more bodies having different temperatures can exchange their heat in several ways

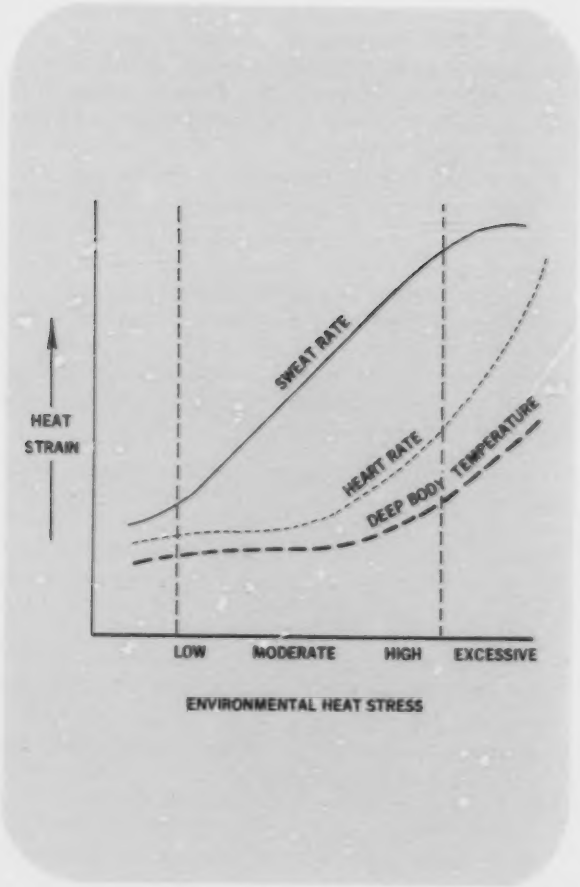
- **convection** is a mechanism of heat exchange through a medium such as air or water
- **conduction** is the transfer of heat between two bodies in contact
- **radiation** is a heat loss due to the emission of heat rays from hotter to cooler surfaces

Conduction is **not** a direct route of heat loss to the environment for the human body—most of the body is in contact with the clothing. Heat rays (radiation) do **not** need a medium like air or water for their transfer. Thus, hot walls in a mine will not only warm the mine air through convection, but also will emit heat directly through radiation and affect persons working in the area.

Muscular work can increase the heat production in the body 10 to 20 times that at rest. The excess heat generated in the body is dissipated through convection, radiation and evaporation. When the body is at rest, the combination of convection and radiation accounts for about three-fourths of the dissipated body heat; and the remaining one-fourth is lost through evaporation. Heat loss through evaporation can take place in the following ways:

- sweat evaporation through almost two million sweat glands in the skin
- saturation of the inhaled air in the lungs with water vapor
- invisible loss of water through the skin without involvement of the sweat glands

Any increase in physical activity calls for more intense evaporation from the skin because heat losses from the lungs and through convection and radiation are **not** enough to keep the body temperature steady.




**Changes in the sweat rate, heart rate, and the core temperature of workers subjected to various degrees of heat stress.**

### Heat Stress and Heat Strain

The human body, when exposed to a wide range of increasing heat loads, can mobilize its resources and restore a balance between heat gain and heat loss. This leads to a new steady core temperature at a somewhat higher level.

**Heat stress** refers to the total heat-related load on the individual from both environmental and metabolic sources.

An increasing environmental heat stress causes changes in sweat rate, heartbeat rate, and body core temperature of the affected individual.

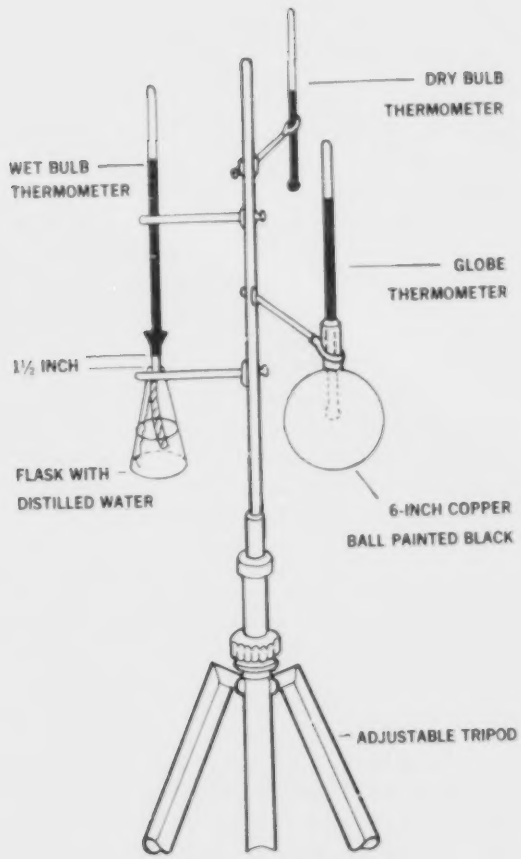
**Heat strain** refers to the adjustments made by the individual in response to the heat stress. These adjustments include biochemical, physiological, and psychological processes.

Healthy and physically fit persons are able to work under heat strain as long as sweat evaporation takes place; by contrast, persons with health problems have a limited capacity for heat strain endurance.

An increase in the sweat rate is the first sign of the heat strain. The steady rise of the sweat rate causes an excessive wetting of the skin. Extended exposure to heat will cause a decline in sweat rate. The sweat gland fatigue and consequent reduction in sweat production indicates a very high level of heat strain.

Some people have no sweat glands at all; such a condition should disqualify them from working in hot environments.

Individuals working in hot areas under emergency conditions (mine rescue workers) and highly motivated individuals working in nonemergency conditions may overstrain themselves. To prevent this kind of strain, the workloads may be reduced, more recovery time may be allowed, or cool rest areas may be provided.




## EVALUATION OF HEAT STRESS

**The standard set of instruments used in the field for Wet Bulb Globe Temperature (WBGT) measurements.**

### What Constitutes a "Hot" Work Site

High or moderately high levels of work produce a great deal of heat in the body. Moreover, the following factors add to the discomfort of a hot work site:

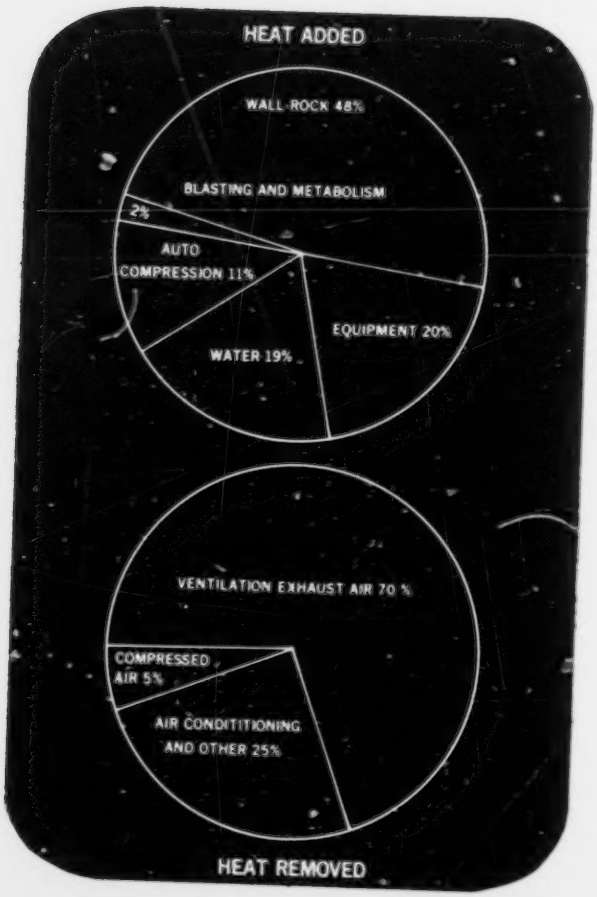
- high air temperatures
- high surface temperatures
- high atmospheric humidity
- relatively low air movement

Here is one definition of hot working place:

**Hot work site** means any combination of air temperature, humidity, radiation and wind speed that exceeds a wet bulb globe temperature of 79°F.

The wet bulb globe temperature is measured with the help of a cluster of thermometers adapted to measure various work site temperatures:

- **dry bulb** thermometer is used to measure the temperature of mine air to get an estimate of convective heat exchange in the mine work area
- **wet-bulb** thermometer reading and its comparison with the dry-bulb thermometer reading is used as an estimate of evaporative heat exchange
- **globe-thermometer** reading indicates the radiative heat coming from the surfaces around the work site
- the temperatures indicated by three thermometers are used in a formula which produces the wet bulb globe temperature (WBGT). If the WBGT exceeds 79°F, the work site is "hot" according to the above definition




**HEAT BALANCE IN A HOT MINE**

**The heat sources are shown on top and the heat-removing mechanisms on lower part of the figure. Note that ventilation is the most important heat-removing mechanism in underground mines.**

## CONTROL OF HEAT STRESS IN MINING

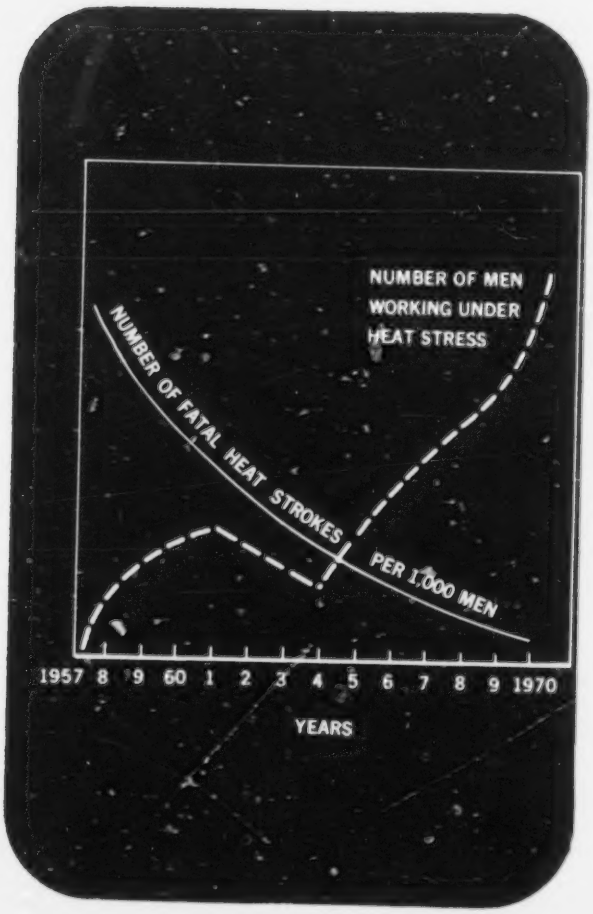
### Proper Work Practices

Generally speaking, work site temperatures, humidity, and air movement can be controlled to lower the heat load and to provide tolerable working conditions in hot mines. At a point, however, these control measures fail to prevent the temperature rise in a worker's body core and proper work practices may be the only heat-stress control measure.

The objective of a good work practice in a hot work site is to prevent the body core temperature from rising above 100°F (38°C). The excessive heat gain must be offset by adequate periods of heat loss.

Desirable work practices include the following:

- increasing workers' heat tolerance by a heat acclimatization (see the next page), and by increasing their physical fitness
- a work-rest regimen--frequent breaks and reasonably short work periods
- pacing a task
- performing heavy tasks in cooler areas or at cooler times
- rotating personnel on hot jobs
- providing readily accessible cooler rest areas, cool--50 degrees to 60 degrees F (10 degrees to 15 degrees C)--drinking water, and encouraging all workers to drink a cup of water every 15 to 20 minutes
- for persons not on a restricted salt diet by physician's orders, a heavier use of salt at meals and drinking slightly salted water (about one level tablespoon salt to fifteen quarts of water)




**Reduction in the number of fatal heatstrokes in South African gold mines as a result of selection and acclimatization of miners.**

### Long-Term Adjustment of Individuals to Heat Stress

Repeated exposure to heat stress may increase the body's tolerance to heat. **Acclimatization** is a long-term adjustment of an individual to a stress. An acclimatized person can perform many tasks in a hot and humid work site where a non-acclimatized person cannot work.

A person should be given enough time for adjustment to a hot work site where the wet bulb globe temperature (WBGT) exceeds 79°F. A recommended six-day acclimatization schedule calls for the miner to work in the hot work site for 50 percent of the time on the first work day, and an additional 10 percent of the time on the days that follow the first day:

| | |
|---|---|
| First day | 50 percent exposure |
| Second day | 60 percent exposure |
| Third day | 70 percent exposure |
| Fourth day | 80 percent exposure |
| Fifth day | 90 percent exposure |
| Sixth day | 100 percent exposure |

Acclimatized workers who return after nine or more consecutive calendar days of leave, should undergo a four-day acclimatization schedule:

| | |
|---|---|
| First day | 50 percent exposure |
| Second day | 60 percent exposure |
| Third day | 90 percent exposure |
| Fourth day | 100 percent exposure |

The mining industry in South Africa has made a good deal of progress in reducing the incidence of heatstroke through selection and acclimatization of miners.

**Miners working in hot areas should know about the hazards of heat stress.**

## Education

A mine supervisor who is knowledgeable about the symptoms of heat disorders can recognize heat stress areas and take corrective action for workers who display heat-related symptoms. Underground miners tend to work in a self-paced manner due to the nature of mining; even so, supervisors with an understanding of heat stress should look out for miners who may be straining themselves.

A person subject to heat stress may **not** be able to recognize the strain symptoms. This is why all miners working in hot areas should know the following:

- what are the signs of imminent heat illness
- how to administer first aid to heat stress victims
- how to reduce the heat stress

Acclimatization and education of new employees to heat stress should be conducted at the same time. New miners should be warned against trying to keep up with active acclimatized miners during the initial stage of acclimatization.

**Medical surveillance is recommended for miners who work in hot work sites.**

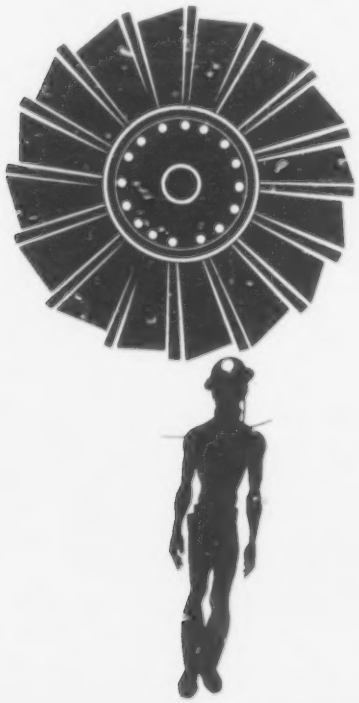
## Medical Surveillance

Medical surveillance can be set up for miners who may be working in hot work sites. This will require medical examination by a physician for all personnel who are to be assigned to hot jobs for the first time. The physician will examine the condition of the heart, blood vessels, kidneys, liver, glands of internal secretion, respiratory system, and the skin.

The incidence of heat stroke, heat exhaustion, and heat cramps should be reported. Such reports will be useful for future heat stress studies.

## Heat Stress Control Through Engineering

Mine planning, ventilation and air conditioning may reduce the heat stress to acceptable levels. Proper mine planning will provide for conveniently available cool rest areas and allow the worker to take the needed rest where he can cool off. When natural cooler air is not available, air conditioning becomes necessary.



**Ventilation and air conditioning may reduce the heat stress in hot work sites.**

**The solar heat load can be reduced by the use of a canopy.**

The sources of heat in surface mines and mills include the sun, machines, dryers, and the kilns. The solar heat load can be reduced by the use of a canopy in most cases. The radiant heat from dryers and kilns can be controlled by shielding. The heat gain by the operator's body is partially lost through evaporation; therefore dry air moving past the body can be helpful.

Wall-rock heat is the major source of heat in many underground mines. Ventilation is the best method of lessening the effect of wall-rock heat on miners. Sometimes air cooling or conditioning is necessary.

All powered equipment—diesel engines, electric motors, compressed air equipment—contributes to the heat load of an underground mine. Generally, most lighting systems convert energy to heat. Excess heat can be reduced by using more efficient equipment and providing efficient ventilation in the mine.

Ground water flowing through hot rock formations becomes hot. The transfer of heat from the ground water to the underground mine air can be controlled by using covered ditches or insulated piping for a speedy transfer of hot waters to the surface.

From 50 to 100 percent of the energy set free in blasting shows up in the form of heat. Efficient blasting procedures will reduce the unwanted release of heat into the mine air.

A part of the miner's body metabolic energy is released to the mine air. In a crowded work site metabolic heat can be a problem. Automation and remote control of mining will serve as a control measure where metabolic heat is a problem.

**All miners working in hot areas should know how to administer first aid to a heat stress victim.**

## HEAT DISORDERS—FIRST AID FOR HEAT STRESS VICTIMS

### Heat Stroke

Heat stroke has three major signs:

- hot dry skin of red, spotted, or bluish or purplish coloration
- rising, high body temperature
- brain disorders—mental confusion, delirium, fainting, convulsions, and coma

Unless promptly and properly treated, heat stroke may be fatal. The victim may suffer permanent brain injury and complications such as kidney, liver, and blood circulation disorders. Survival and complete recovery after undergoing an initially high body temperature is possible if prompt and effective cooling is provided. The victim must be moved to a cool area; further, soaking of the victim's clothing with cold water and fanning will cool the body.

Heat stroke results from the failure of the heat regulatory system in the body. The failure of sweating leads to the loss of evaporative cooling of the skin and an uncontrolled rapid rising of the body temperature. In milder cases of heat disorders, sweating may still be evident in spite of high body temperature.

**Heat fainting happens when the brain suffers from a temporary shortage of blood supply.**

**Heat cramps may be the result of salt deficiency in the body.**

### Heat Fainting

Heat fainting is the most common form of heat disability. It happens when the individual is in a standing position, the return of venous blood to the heart is **not** sufficient and the brain suffers from a temporary shortage of blood supply. The victim's prostration helps to restore the normal blood circulation. The victim should be removed to a cooler area. A prompt and complete recovery usually follows the prostration.

### Heat Exhaustion and Heat Cramps

The signs of heat exhaustion include weakness, lowered blood pressure, signs of fainting, tiredness, nausea and headache, even between work activities. Clammy and moist skin and a pale, muddy, or flushed look are also present. If sitting, the victim may faint on getting up. Heat cramps are painful contractions of skeletal muscles in arms, legs, or the abdominal area of the body.

Heat exhaustion and heat cramps are the results of salt deficiency in the body. The loss of salt through sweating and the urine may exceed the salt intake. Drinking large volumes of water without replacing the lost salt will allow the water to enter the muscles and cause spasms. Workers not on a restricted salt diet by physician's orders should use more salt at meal time to make up for the loss of salt. Salt tablets irritate the stomach and should not be used. Painful spasms of muscles can be promptly relieved by intravenous infusion of salted liquid. In cases of high salt deficiency, restoration of body salt balance takes several days.

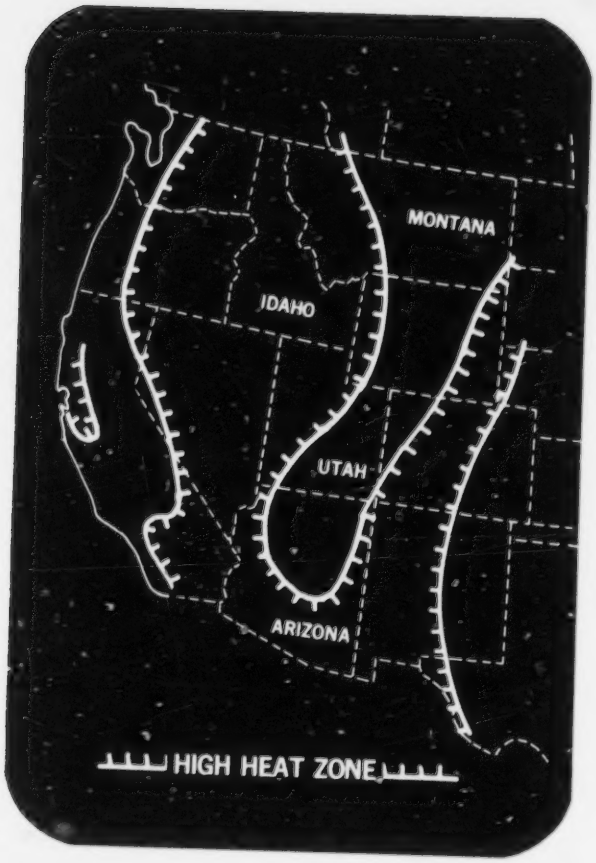
**In hot work sites, cool drinking water containing 0.1 percent salt should be used.**

### Water-Deficiency Heat Exhaustion

Some individuals feel that by restricting their water intake in hot jobs they reduce the amount of sweat dripping from their faces and into their eyes. They should be convinced that they are trading safety for comfort and that a voluntary restriction of their water intake may lead to water-deficiency heat exhaustion and even heat stroke. The risk of dehydration is greater if the major part of the daily meals is dry or dehydrated. The victim of water deficiency and heat exhaustion is thirsty. In mild cases, rest in a cool area and the taking of water results in a speedy recovery.

### Prickly Heat

Prickly heat or heat rash is in the form of tiny red blisters in the affected skin area. Affected areas of the skin are treated with mild drying lotions; cooled sleeping quarters allow for the drying of the skin between heat exposures. Prickly heat is related to the wasting away (maceration) of the skin by the continuous presence of unevaporated sweat.




**Certain areas of earth's crust release more heat than others; mines located along high heat zones are normally hot. This map shows the zones of high heat in Western United States.**

## SUMMARY

Some deep mining operations, located along high heat zones in western United States, represent hot work sites. Workers performing hazardous jobs and exposed to temperatures in excess of 80°F are known to have high accident rates. Intensive physical activity in hot work sites results in higher sweat and heartbeat rates. Long-term exposure of non-acclimatized persons to heat stress is unhealthy and unproductive. Selection, acclimatization, and education of employees for working in hot work sites, coupled with an effective engineering control of heat at the work site, will provide a healthy work environment in mines and mills.

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## GLOSSARY OF TERMS

**Carbohydrates**—organic compounds, such as sugar, starches, celluloses, which form the supporting tissues of plants and are important food for animals.

**Dehydration**—loss of water or body fluids.

**Metabolism**—chemical changes in living cells by which energy is provided for vital processes and activities and new material assimilated to repair the waste.

**Wall Rock**—the country rock immediately adjoining mineral desposits.

## ABOUT THE AUTHOR

### Leo Misagi

Leo Misagi, Sc.D., P.E., Mining Engineer, is also a health physicist and the author of other safety manuals in this series, a score of technical papers, handbooks, and articles for professional periodicals, including a study of heat stress in mining, performed by him and three other MSHA health and safety professionals whose names appear in this manual's bibliography.

Dr. Misagi, formerly Chief of the Academy's Department of Resident Education, has worked in underground coal and metal/nonmetal mines in the Middle East, taught at the New Mexico Institute of Mining and Technology, and held various positions at the U.S. Bureau of Mines in Pittsburgh, Pennsylvania, MSHA's Technical Support Center in Denver, Colorado, and MSHA headquarters in Arlington, Virginia.

Notes

SAFETY MANUALS

Accident Investigation
Accident Prevention
Coal Mine Maps
Coal Mine Roof and Rib Control
Coal Mining
Electrical Hazards
Fault Tree Analysis
Fire Safety
First Aid
Heat Stress in Mining
Industrial Hygiene for Healthier Miners
Job Safety Analysis
Laboratory Safety
Mine Escapeways
Mine Gases
Mine Ventilation
Permissibility - Electric Face Equipment
Personal Protective Equipment
The Radiation Hazard in Mining
Safety Tips for Underground Coal Mining
System Safety Engineering
Winter Alert